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Research Article

Physicochemical and Bacteriological Assessment of Domestic Water from Pindiga Pond, Akko L.G.A., Gombe State, Nigeria

***Ndukwe, Nelson Nwachukwu[1], Tyohemba, Samuel Terhide[2], Habiba Usman Aliyu[1] and Chibundu, Nelson Okwudiri[3]**

[1]Department of Microbiology, Federal University Kashere, Gombe State, Nigeria. P.M.B. 0182 Gombe, Gombe State, Nigeria
[2]Department of Biochemistry and Molecular Biology, Federal University Kashere, Gombe State, Nigeria. P.M.B. 0182 Gombe, Gombe State, Nigeria
[3]Department of Microbiology, Federal University of Technology, Owerri, Imo State, Nigeria. P.M.B. 1526, Imo State, Nigeria
***Corresponding Author's email**: nelsonndukwe29@gmail.com; **Phone: +2347034884365**

ABSTRACT
Access to safe water is a major health challenge in developing countries like Nigeria. This study evaluated the physicochemical, heavy metal, and bacteriological quality of domestic water from Pindiga Pond, Akko Local Government Area, Gombe State, Nigeria. Water samples from ten points were collected between March and May 2025 and analysed. Standard methods determined physicochemical parameters, heavy metals, bacteriological quality, and water quality index (WQI). Data were analysed using descriptive statistics and One-Way Analysis of Variance (ANOVA) at 95% confidence interval. Most physicochemical parameters were within acceptable limits, including pH (6.42–6.76), turbidity (0.33–1.44 NTU), and total dissolved solids (TDS (19.2–90.3 mg/L). However, dissolved oxygen (1.1-1.9 mg/L) and iron (1.37-2.56 mg/L) exceeded WHO limits. Heavy metals Cu^{2+}, Cr^{3+}, Mn^{2+}, and Zn^{2+} were below detection limits. Bacteriological analysis showed severe faecal contamination, with total coliform counts (9.5-24 MPN/100 mL) and *Escherichia coli* in 70% of the samples. *Salmonella typhi* and *Vibrio cholerae* were also isolated. Statistical analysis showed significant variation ($p < 0.05$) among sampling points. The water quality index ranged from 1100.79 to 1216.34, indicating samples were unfit for human consumption. While chemical composition meets most standards, bacteriological contamination makes it unfit for domestic use without treatment. Control measures, including point-of-use treatment, sanitation improvement, and monitoring should be implemented.

Keywords: Bacteriological contamination; Heavy metals; Pindiga Pond; Physicochemical parameters; Water quality index

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INTRODUCTION

Water is an indispensable resource that supports life on Earth and sustains human life. It exists in three states: solid, liquid, and gas, and covers approximately three-quarters of the Earth's surface. Despite its abundance, access to clean water remains a global challenge, particularly in developing countries (Bellinger, 2024). Water serves as a universal solvent for countless reactions; however, its quality is often compromised by pollutants (Raghavendra, 2024). Globally, access to clean and safe water is a significant challenge. The World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) reported that approximately 4.5 billion people lack safely- managed sanitation and 2.1 billion have no safe drinking water at home (WHO and UNICEF, 2017). Among them, 844 million lack basic water services, and 159 million, mostly in sub-Saharan Africa, rely on untreated water sources (WHO, 2017a; WHO and UNICEF, 2017). In Nigeria, 60 million people lack potable water (Bisi-Johnson *et al.,* 2017).

Access to potable water is particularly acute in Nigeria, where rural populations rely on untreated natural water sources (Irene *et al.,* 2025). Reports from the National Bureau of Statistics show that over one-quarter of rural dwellers in northern Nigeria depend on surface water sources for domestic use (Sawyer *et al*., 2024). This dependence exposes communities to waterborne pathogens through contamination with human and animal wastes. Studies have shown that microbial pathogens such as *Escherichia coli*, *Salmonella typhi*, *Vibrio cholerae*, and *Shigella dysenteriae* cause diseases including cholera, diarrhoea, dysentery, and typhoid fever (Dufour *et al.,* 2003; Sharma *et al.,* 2023). According to the WHO (2019), 80% of diseases in developing countries are water-related, with poor sanitation contributing to 3.1% of global deaths. The implications for Nigeria are concerning, given its population growth and strain on water infrastructure. Water quality deterioration occurs when the chemical, physical, or biological properties of water are altered beyond acceptable limits, rendering it unsuitable for domestic and ecological use. Polluted water endangers aquatic organisms and humans, often transmitting diseases (Schwarzenbach *et al.,* 2010). In Pindiga, Akko Local Government Area (L.G.A.) of Gombe State, the challenges include both water scarcity and the safety of the available sources (Buba *et al*., 2022). Households depend on surface ponds and shallow wells, which are vulnerable to contamination by agricultural runoff, animal waste and household effluents (Bhateria and Jain, 2016). Heavy metals, such as iron, copper, zinc, and chromium, along with excess nutrients, such as nitrates and phosphates, accumulate in domestic water sources, posing health risks. The presence of *E. coli* and other faecal coliforms serves as a biological indicator of contamination, indicating faecal pollution and the presence of potential enteric pathogens (Izah *et al.,* 2016; Li *et al.,* 2021).

The evaluation of physicochemical and bacteriological parameters of water is essential for determining its quality and suitability for human consumption. Parameters such as pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), and concentrations of nitrates and phosphates indicate pollution levels and organic and inorganic contamination in water (Verma *et al*.,2025). Regular water quality monitoring helps identify contamination sources and assess compliance with established standards, such as those set by the World Health Organization (WHO, 2022) and the Standards Organization of Nigeria (SON, 2007). Poor monitoring and management of domestic water sources have contributed to waterborne disease outbreaks in Nigeria and other developing regions (Perveen and Amar, 2023).

Despite the growing awareness of water pollution in Gombe State, limited empirical data are available on the physicochemical and bacteriological characteristics of domestic water sources in Pindiga. Previous research has primarily focused on larger cities, neglecting smaller communities that rely heavily on untreated water. This gap necessitates localised studies to provide accurate, evidence-based data for improving water management policies. Consequently, this study sought to assess the physicochemical and bacteriological qualities of domestic water sources in Pindiga, Akko L.G.A., Gombe State, Nigeria.

MATERIALS AND METHODS

Study Area and Site Description

The study was conducted in the Pindiga Pond, located along Kashere Road in the Akko Local Government Area, Gombe State, Nigeria. Pindiga lies at approximately 9.98°N latitude and 10.93°E longitude, with an elevation of 541 m above sea level. The area experiences a tropical wet and dry climate, with annual rainfall ranging between 850 and 1100 mm and temperatures varying from 22°C to 35°C. The population is approximately 163,356 people (Kolawole *et al*., 2023), and the community relies mainly on boreholes, wells, and ponds for domestic and agricultural water supplies. Agricultural runoff, open defaecation, and improper solid waste disposal are common activities that render local water bodies susceptible to contamination by faecal pathogens. Therefore, geographical and socioeconomic contexts provide a relevant setting for assessing the physicochemical and bacteriological quality of water sources.

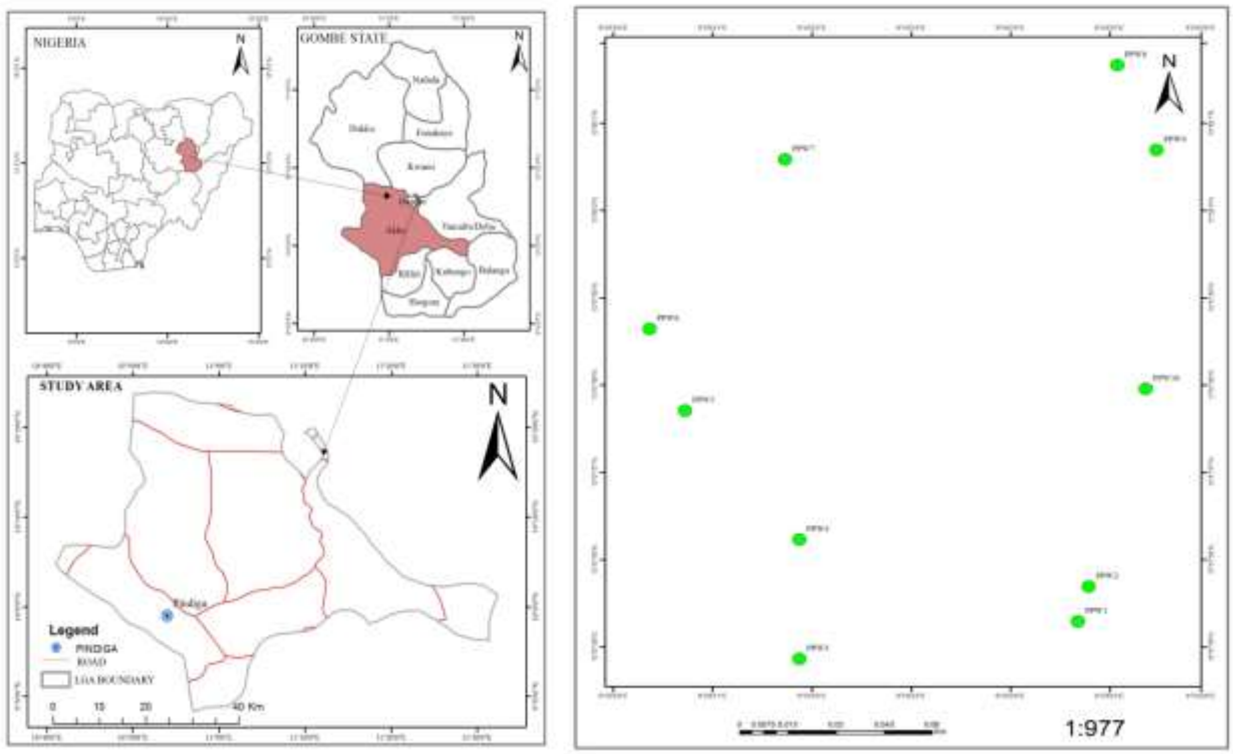

Figure 1: Map showing the ten (10) Sampling points in the Pindiga pond

Table 1: Coordinates of sampling points in the Pindiga pond

S/no	Code	Latitude	Longitude
1	PSW 1	09.99019°N	10.96536°E
2	PSW 2	09.99022°N	10.96517°E
3	PSW 3	09.98967°N	10.96524°E
4	PSW 4	09.98941°N	10.96562°E
5	PSW 5	09.98909°N	10.96603°E
6	PSW 6	09.98899°N	10.96629°E
7	PSW 7	09.98937°N	10.96682°E
8	PSW 8	09.99030°N	10.96713°E
9	PSW 9	09.99041°N	10.96686°E
10	PSW 10	09.99038°N	10.96610°E

Collection of Samples

Water samples were collected from ten (10) representative sampling points around Pindiga Pond using a Global Positioning System (GPS) for geolocation accuracy. Sampling was conducted between March and May 2025, representing the early wet season. Sterile 1-litre polyethylene bottles were used for physicochemical analysis, and sterile 100 mL bottles were used for bacteriological examination. All containers were pre-rinsed with the respective water sources before collection. The samples were labelled, preserved at 4°C in ice-packed coolers, and transported within six hours to Environmental Microbiology and Chemistry Laboratory at Federal University Kashere for analysis. Acidification with 2 mL of concentrated nitric acid per litre was performed to stabilise the heavy metals. Sampling and preservation protocols followed the standard guidelines established by the American Public Health Association (APHA, 2017).

Physicochemical Analysis

The physicochemical parameters analysed included temperature, pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), total hardness, and nitrate, phosphate, chloride, and sulfate concentrations. In situ measurements of temperature and pH were performed using a portable

Hanna H198107 multiparameter meter. Turbidity was measured using a Hach 2100N turbidity meter, and EC and TDS were determined using a Hach conductivity meter. Dissolved oxygen and BOD were assessed using the Winkler titrimetric method and a five-day incubation procedure. Nitrate, phosphate, and sulfate concentrations were determined using colorimetric and titrimetric methods, as outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, 2017). For heavy metal analysis, 75 mL of each water sample was digested with 25 mL of nitric acid in a Kjeldahl flask, reduced to one-fourth of its original volume, cooled, filtered, and analyzed using an atomic absorption spectrophotometer (AAS Model 210 VGP, Buck Scientific). All analyses were performed in triplicate, and the results were compared with the permissible limits established by the World Health Organization (WHO, 2008) and the Nigeria Standard Drinking Water Quality (NSDWQ, 2007).

Bacteriological Analysis

The bacteriological quality of the samples was evaluated using multiple-tube fermentation (MTF) and membrane filtration (MF) methods. Total heterotrophic bacterial counts were determined by plating 1 mL aliquots on Nutrient agar and incubating them at 37°C for 24 h. For total and faecal coliform detection, the Most Probable Number (MPN) method was employed. Serial dilutions of the water samples (10, 1, and 0.1 mL) were inoculated into MacConkey broth containing inverted Durham tubes and incubated at 37°C for 24–48 h. Gas production indicated presumptive coliforms in the sample. Positive tubes were transferred to brilliant green lactose bile (BGLB) broth for confirmation and subsequently streaked onto eosin methylene blue (EMB) agar plates. Typical colonies with a metallic green sheen were identified as *Escherichia coli* and confirmed by biochemical testing following Bergey's Manual of Determinative Bacteriology. Other isolates were identified using standard morphological and biochemical assays, including catalase, oxidase, indole, citrate, motility, methyl red, and Voges-Proskauer tests. All bacteriological procedures adhered to the APHA (2017) and WHO (2017b) recommendations.

Water quality index

The WQI was calculated using the standards of drinking water quality recommended by the World Health Organization (WHO, 2008) and Nigeria Standard Drinking Water Quality (NSDWQ,2007). The WQI was calculated using the weighted arithmetic method originally described by Kpikpi and Bubu-Davies. (2021). The weighted arithmetic WQI is represented in Equation (1), and its classification status is displayed in Table 2.

$$WQI = \frac{\Sigma_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

where n signifies the number of variables or parameters, Wi represents the unit weight for the ith parameter, and Qi is the quality rating (sub-index) of the ith water quality parameter. The unit weights (Wi) for the different water quality parameters were inversely related to the recommended standards for their respective parameters:

$$w_i = \frac{k}{S_n} \quad (2)$$

$$k = \left(\frac{1}{E\left(\frac{1}{S_n}\right)}\right) \quad (3)$$

where *Sn* represents the standard value for the *i*th parameter, and *K* denotes the proportional constant, and the value of *K* has been set to 1.

The calculation of the quality rating or sub-index (Qi) is determined by the following formula:

$$Q_i = 100 \times \frac{[(V_0 - V_i)]}{[(S_n - V_i)]} \quad (4)$$

In this context, Vo refers to the measured value of the ith parameter at a particular sampling location, and Vi signifies the ideal value of the ith parameter in pure water. According to Inayathulla and Paul. (2013), all ideal values (Vi) for drinking water are considered zero, except for pH and DO values. For pH, the ideal value is 7.0, which corresponds to natural or pure water, whereas the acceptable value for polluted water is 8.5. Similarly, for DO, the ideal value is 14.6 mg/L, whereas the standard permissible level for drinking water is 5 mg/L.

Data Analysis

All experimental data were subjected to descriptive statistical analysis using IBM SPSS version 22 to determine the means and standard deviations of each parameter. One-way analysis of variance (ANOVA) was used to evaluate significant variations among sampling sites at a 95% confidence level ($P < 0.05$). Data visualisation and computation were performed using GraphPad Prism 8. The results were compared with the WHO (2008) and NSDWQ (2007) standards to assess the suitability of the water for domestic consumption.

RESULTS

Physicochemical Parameters

Physicochemical analysis of the water samples from Pindiga revealed various characteristics (Table 2). The water temperature ranged from 29.8°C to 32.7°C, with a mean of 31.5°C. This is consistent with the typical values for tropical freshwater. The pH values ranged from 6.42 to 6.76, with a mean of 6.59, which is slightly acidic but within the acceptable range of 6.5–8.5 for drinking water, as recommended by the WHO (2008) and NSDWQ (2007). Electrical conductivity (EC) values ranged from 125.1 to 172.3 µS/cm, suggesting freshwater conditions, well below the WHO (2008) guideline limit of 500 µS/cm for potable water. The turbidity values ranged from 0.33 to 1.44 NTU, all below the WHO limit of 5 NTU for drinking water. The total dissolved solids (TDS) concentrations varied from 19.2 to 90.3 mg/L, indicating low concentrations of dissolved solids, which is favourable for water quality. Dissolved oxygen (DO) levels were low, ranging from 1.1 to 1.9 mg/L, with three sampling points (PWS4, PWS7, and PWS10) falling below the WHO (2008) recommended minimum of 5 mg/L, suggesting possible oxygen depletion in these water bodies. The biochemical oxygen demand (BOD) values ranged from 0.2 to 0.5 mg/L, indicating a low organic matter load in water samples. Descriptive statistical analysis showed a mean pH of 6.59 ± 0.15, which was consistent across sampling locations, with no significant differences ($p > 0.05$). Temperature also did not show any significant variation ($p > 0.05$). However, TDS and turbidity varied significantly across the sampling points ($p < 0.05$), particularly in areas closer to agricultural runoff, where turbidity and TDS were higher.

Heavy Metal Analysis

The concentrations of heavy metals in the water samples were generally low (Table 3). Iron (Fe) concentrations ranged from 1.37 mg/L to 2.56 mg/L, which exceeds the WHO (2008) guideline limit of 0.3 mg/L for drinking water. The magnesium (Mg) levels ranged from 3.77 to 3.98 mg/L, which is not within the acceptable limits for safe drinking water. Other heavy metals, such as copper (Cu), chromium (Cr), manganese (Mn), and zinc (Zn), were not detected in any of the samples. These results suggest that while the iron levels in the water are concerning, other toxic metals such as copper and chromium are absent in the water. High iron concentrations may be attributed to natural geological sources or local human activities, including industrial and agricultural runoff. Statistical analysis of iron concentrations showed a significant variation between different sampling points ($p < 0.05$), with higher iron concentrations found in samples located near the industrial areas. The mean iron concentration was 1.92 ± 0.46 mg/L, which is significantly higher than the WHO-recommended limit.

Bacteriological Quality

Bacteriological analysis revealed significant contamination of the water samples (Table 4, 5, 6 and 7). Total coliform counts, measured using the Most Probable Number (MPN) method, ranged from 9.5 to 24 MPN/100 mL, with the highest count observed in PWS10. This exceeds the permissible limit of 0 MPN/100 mL, set by the WHO (2008) for safe drinking water. The total heterotrophic bacterial count (THBC) ranged from 8.5×10^4 to 1.1×10^4 CFU/mL, with PWS3 showing the highest bacterial load (Table 4). Twelve bacterial species were isolated from the water samples, including *Escherichia coli* (70% occurrence), Salmonella Typhi (30%), and *Vibrio cholerae* (30%). These bacteria are pathogenic and associated with gastrointestinal diseases. Other bacterial isolates included *Bacillus subtilis*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. These findings indicate significant faecal contamination, rendering the water unsafe for domestic use according to the WHO and NSDWQ (2007) guidelines. Statistical analysis of the bacteriological data indicated a significant difference in coliform and *E. coli* counts between the sampling sites ($p < 0.05$). The mean total coliform count was 16.2 ± 5.1 MPN/100 mL, which was significantly higher than the WHO (2008) threshold of 0 MPN/100 mL. The highest bacterial contamination was found near areas with poor sanitation and agricultural runoff, confirming the impact of localised pollution sources.

Water Quality Index (WQI)

The Water Quality Index (WQI) was computed using 14 essential parameters, including 12 physicochemical variables and two heavy metals (Fe and Mg). The WQI values across the ten sampling points ranged from 1100.79 to 1216.34, reflecting a significant deviation from the permissible standards. Elevated iron (1.37–2.56 mg/L) and magnesium (3.77–3.98 mg/L) concentrations, coupled with low dissolved oxygen (1.1–1.9 mg/L), were the major contributors to the high index values. In contrast, parameters such as pH, TDS, and turbidity remained within acceptable limits. The computed WQI classified all sampling points as unsuitable for drinking, indicating that Pindiga pond water poses potential health risks and requires treatment before domestic or potable use (Table 8).

Table 2: Physicochemical Parameters of Water Samples from Pindiga Pond, Akko L.G.A., Gombe State

Parameter (unit)	PWS1	PWS2	PWS3	PWS4	PWS5	PWS6	PWS7	PWS8	PWS9	PWS10	WHO (2008)		NSDWQ (2007)
											HDL	MPL	
Temp (°C)	32.7 ± 0.8	32.6±0.7	32.1±0.9	31.4±1.0	31.5±0.6	30.8±0.5	30.9±0.4	30.6±0.7	29.8±0.9	30.8±0.5	20 -30	40	27-28
pH	6.53±0.12	6.76±0.15	6.56±0.10	6.63±0.11	6.51±0.09	6.42±0.14	6.65±0.08	6.59±0.13	6.68±0.07	6.66±0.10	7.0-8.5	6.5- 9.2	6.5-8.5
EC (µs)	172.3±1.2	167.1±1.4	154.8±1.1	140.6±1.5	130.4±0.9	125.1±1.3	140.8±1.0	154.1±1.6	125.4±0.8	131.3±1.1	500	1400	150
Turbidity (NTU)	0.51±0.18	0.13±0.05	1.43±0.21	1.07±0.16	0.97±0.14	0.64±0.12	0.46±0.10	0.91±0.15	0.97±0.17	1.44±0.22	5	25	-
TDS (mg/L)	90.3±1.1	85.3±1.3	77.3±0.9	19.2±0.7	38.6±0.8	20.5±0.6	21.2±0.5	19.6±0.4	24.6±0.7	31.7±0.9	500		500
DO (mg/L)	1.7±0.15	1.8±0.18	1.6±0.14	1.9±0.16	1.2±0.10	1.4±0.12	1.1±0.09	1.3±0.11	1.8±0.17	1.1±0.08	14	6	4-7
BOD (mg/L)	0.3±0.05	0.3±0.04	0.2±0.03	0.3±0.05	0.4±0.06	0.3±0.04	0.2±0.03	0.3±0.05	0.5±0.07	0.5±0.06	4		3
NO_3^- (mg/L)	7.03±0.25	7.08±0.27	7.32±0.30	7.38±0.32	7.40±0.29	6.88±0.22	4.12±0.18	4.56±0.20	3.98±0.15	3.00±0.12	50		50
PO_4^{2-} (mg/L)	3.12±0.20	3.44±0.22	3.96±0.25	4.20±0.28	4.08±0.26	3.80±0.24	4.16±0.27	4.96±0.30	6.34±0.35	8.70±0.40	200		≤ 5
Salinity (ppt)	0.3±0.05	0.3±0.04	0.3±0.05	0.2±0.03	0.3±0.04	0.2±0.03	0.3±0.05	0.3±0.04	0.2±0.03	0.3±0.04	-		-
SO_4^{2-} (mg/L)	7.24±0.30	6.32±0.25	6.02±0.22	5.88±0.20	4.01±0.18	2.20±0.12	0.53±0.05	1.98±0.10	1.64±0.09	0.56±0.06	200	400	100
Total Hardness (mg/L)	17.6±0.4	16.4±0.3	17.6±0.5	17.9±0.4	16.0±0.3	15.3±0.4	16.2±0.3	16.5±0.4	16.3±0.3	16.7±0.4	500		150

Keys: WHO= world health organization, NSDWQ= Nigeria standard drinking water quality, Temp.= temperature, TDS= total dissolved solid, DO= dissolved oxygen, BOD=biological oxygen demand, Cl= chloride, Mg= magnesium, NO_3= Nitrate, EC=Electrical conductivity, PO_4= phosphates, SO_4= sulphate

Table 3: Heavy Metal Concentrations in Water Samples from Pindiga Pond, Akko L.G.A., Gombe State

Parameter (mg/L)	PWS1	PWS2	PWS3	PWS4	PWS5	PWS6	PWS7	PWS8	PWS9	PWS10	NSDWQ 2007)
Cu^{2+}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0
Cr^{3+}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Mn^{2+}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2
Zn^{2+}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.0
Fe^{2+}	1.74 ± 0.15	1.61 ± 0.14	1.66 ± 0.13	1.68 ± 0.16	1.75 ± 0.17	1.60 ± 0.12	2.56 ± 0.20	1.37 ± 0.11	2.49 ± 0.19	2.14 ± 0.18	0.3
Mg^{2+}	3.91 ± 0.10	3.77 ± 0.09	3.77 ± 0.08	3.80 ± 0.11	3.98 ± 0.12	3.86 ± 0.09	3.81 ± 0.10	3.89 ± 0.11	3.85 ± 0.08	3.90 ± 0.10	0.2

Keys: NSDWQ= Nigeria standard drinking water quality, PWS= Pindiga pond Water Sample, ND=Not Detected.
Mn= manganese, Cr= chromium, Zn= zinc, mg= magnessium, Fe= iron, Cu= copper

Table 4: Total Coliform Count in Water Samples from Pindiga Pond, Akko L.G.A., Gombe State, Using the Most Probable Number (MPN) Method

Sample	Combination of positives			MPN index/g(mL)	95% Confidence limit	
	First	Middle	Last		Lower	Upper
PWS 1	3	2	3	2.9 ± 0.5	0.90	24
PWS 2	2	2	2	3.5 ± 0.6	0.87	14
PWS 3	3	0	2	0.64 ± 0.1	0.17	13
PWS 4	3	3	1	4.6 ± 0.7	0.90	21
PWS 5	3	2	3	2.9 ± 0.5	0.90	24
PWS 6	3	2	1	1.5 ± 0.3	0.37	17
PWS 7	3	1	1	0.75 ± 0.2	0.17	14
PWS 8	2	1	1	0.20 ± 0.05	0.045	9.2
PWS 9	2	2	1	0.28 ± 0.06	0.087	12
PWS 10	3	2	1	1.5 ± 0.3	0.37	17

PWS: Pindiga pond Water Sample. Values are presented as Mean MPN/100 mL ± S.D.

Table 5: Total Heterotrophic Count (THC) in Water Samples from Pindiga Pond, Akko L.G.A., Gombe State

Sample	Total Heterotrophic Count (THC) (CFU/mL)
PWS 1	$(1.8 \pm 0.3) \times 10^4$
PWS 2	$(5.3 \pm 0.6) \times 10^4$
PWS 3	$(8.5 \pm 0.9) \times 10^4$
PWS 4	$(5.9 \pm 0.7) \times 10^4$
PWS 5	$(4.5 \pm 0.5) \times 10^4$
PWS 6	$(4.8 \pm 0.5) \times 10^4$
PWS 7	$(3.9 \pm 0.4) \times 10^4$
PWS 8	$(5.0 \pm 0.6) \times 10^4$
PWS 9	$(1.1 \pm 0.2) \times 10^4$
PWS 10	$(2.9 \pm 0.3) \times 10^4$

PWS: Pindiga Water Sample; CFU: Colony-forming Units.

Table 6: Frequency of Occurrence of Bacterial Isolates in Water Samples from Pindiga Pond, Akko L.G.A., Gombe State

Probable Identity	PWS1	PWS2	PWS3	PWS4	PWS5	PWS6	PWS7	PWS8	PWS9	PWS10	Frequency of Occurrence
B. cereus	_	_	_	_	_	_	+	_	+	_	20%
B. subtilis	_	+	_	_	+	+	_	_	+	_	40%
E. coli	+	+	+	_	+	+	_	+	_	+	70%
Enterobacter aerogenes	_	_	+	_	_	_	_	+	_	_	20%
Klebsiella pneumoniae	_	_	_	+	_	_	_	_	_	_	10%
Proteus mirabilis	_	_	_	_	+	_	_	_	_	_	10%
Pseudomonas auriginosa	_	+	_	_	_	_	_	_	_	_	10%
Salmonella typhi	+	_	_	_	+	_	_	+	_	_	30%
Shigella dysenteriae	_	_	+	_	_	+	_	_	+	_	30%
Staphylococcus aureus	+	+	_	+	_	_	_	_	_	+	40%
Streptococci pyogens	_	_	_	+	_	+	_	_	_	_	20%
Vibrio cholerae	+	_	+	_	_	_	+	_	_	_	30%`

Table 7: Biochemical Characterisation of Bacterial Isolates from Water Samples in Pindiga Pond, Akko L.G.A., Gombe State

Isolate code	Gram Rxn	Morphology	Indole	Citrate	Oxidase	Catalase	Motility	MR	VP	Coagulase	SF	Probable Identity
A	+	Rod	_	+	+	+	+	_	+	+	+	*Bacillus subtilis*
B	+	Rod	_	+	_	+	+	_	+	_	_	*Bacillus cereus*
C	_	Rod	+	_	_	+	+	+	_	_	+	*E. coli*
D	_	Rod	_	+	_	+	+	_	+	_	+	*E. aerogenes*
E	_	Rod	_	+	_	+	_	_	+	+	+	*K. pneumonea*
F	_	Rod	_	+	+	+	+	_	_	_	_	*P. aruginosa*
G	_	Rod	_	+	_	+	+	+	_	+	_	*P. mirabilis*
H	_	Rod	_	_	_	+	+	+	_	_	_	*Salmonella typhi*
I	_	Rod	_	_	_	_	_	+	_	_	_	*S. dysenteriea*
J	+	Cocci	_	+	_	+	_	+	+	_	+	*Staph. aureus*
K	+	Cocci	_		-	-	-	+	-	-	-	*Strep. pyogens*
L	+	Rod	+	+	+	+	_	_	_	+	_	*Vibrio cholera*

Table 8: WQIs for the water samples collected from the Pindiga pond

Sampling Point	WQI	Water Quality Category
PWS1	1148.94	Unsuitable (>100)
PWS2	1100.79	Unsuitable (>100)
PWS3	1106.71	Unsuitable (>100)
PWS4	1115.28	Unsuitable (>100)
PWS5	1167.73	Unsuitable (>100)
PWS6	1120.78	Unsuitable (>100)
PWS7	1213.93	Unsuitable (>100)
PWS8	1104.80	Unsuitable (>100)
PWS9	1216.34	Unsuitable (>100)
PWS10	1192.67	Unsuitable (>100)

DISCUSSION

The physicochemical parameters of Pindiga Pond indicate that the water quality is within the general range reported for tropical freshwater systems in Nigeria. The measured temperature (29.8–32.7°C; mean 31.5°C) and slightly acidic pH (6.42–6.76; mean 6.59) align with the findings of Odewade *et al.* (2025), who reported similar physicochemical conditions in groundwater from Katsina State. Abulude *et al.* (2024) recorded pH values between 5.66 and 7.89 (mean 6.88) across southwestern Nigeria, mostly within WHO limits, and attributed the mild acidity to dissolved carbon dioxide and organic acid decomposition in tropical soils. These temperatures are typical of shallow tropical water bodies and influence the microbial activity and chemical equilibria. The pH values fell within the acceptable limits of the WHO (2008) and the NSDWQ (2007) standards, indicating that the water was chemically stable. The electrical conductivity (125.1–172.3 µS/cm) and total dissolved solids (19.2–90.3 mg/L) values suggest low mineralisation, consistent with fresh, non-saline water. Similarly, Sulaiman *et al.* (2025) found that groundwater in Gombe State exhibited low mineralization and a stable ionic balance, consistent with the present findings. Comparable results were also documented by Ojo *et al.* (2021) in Ondo State and by Popoola *et al.* (2019) in southwestern Nigeria, both confirming that most natural water bodies in rural Nigeria show low ionic concentrations and are therefore less susceptible to salinization. The low conductivity (<200 µS/cm) and TDS (<100 mg/L) observed here indicate good ionic quality and freshwater characteristics typical of non-mineralized aquifers. However, the observed dissolved oxygen (DO) concentrations (1.1–1.9 mg/L) were below the WHO minimum requirement of 5 mg/L, indicating poor aeration and possible organic matter decomposition. Odewade *et al.* (2025) attributed similar low DO levels in Katsina State to organic pollution and microbial respiration. In this study, the biochemical oxygen demand (BOD) was low (0.2–0.5 mg/L), suggesting limited degradable organic matter, although the consistently low DO implies ongoing oxygen consumption, likely linked to microbial activity and stagnant conditions. Conversely, the markedly low DO suggests a microbial oxygen demand due to organic matter degradation, a pattern also noted by Adewumi *et al.* (2023) in rural boreholes of Kwara State. Although the biochemical oxygen demand (BOD 0.2–0.5 mg/L) was low, the depressed DO values implied persistent oxygen depletion linked to natural organic inputs and limited re-aeration.

Among heavy metals, iron (Fe) and magnesium (Mg) were the only contaminants exceeding the permissible limits, with concentrations ranging from 1.37 to 2.56 mg/L (mean 1.92 ± 0.46 mg/L). This surpasses the WHO guideline of 0.3 mg/L and aligns with the findings of Popoola *et al.* (2019), who also observed iron as the predominant heavy metal in Nigerian rivers. Iron levels were notably elevated (mean 1.92 ± 0.46 mg/L), corroborating reports by Abulude *et al.* (2024) and Sulaiman *et al.* (2025), who associated high Fe concentrations with iron-bearing geologic formations and reduced subsurface conditions. In some cases, anthropogenic sources, such as corroding metallic pipes and agricultural runoff, may also contribute (Sulaiman *et al.,* 2025). The significant spatial variation in Fe concentrations ($p < 0.05$) implied localised influences, particularly near residential and farming areas. Mg concentrations were low (3.77–3.98 mg/L), and heavy metals such as copper (Cu), chromium (Cr), manganese (Mn), and zinc (Zn) were below the detection limits. Oyem *et al.* (2015) reported negligible levels of Cr, Cd, and As in groundwater from Agbor and Owa communities, concluding that water in these regions posed no significant heavy metal risk. Similarly, Ojo *et al.* (2025) observed only trace amounts of Fe in boreholes across Akure, suggesting that Fe is often the dominant natural contaminant in Nigerian groundwater, whereas other metals remain within safe limits. The absence of toxic heavy metals in Pindiga Pond reflects minimal industrial pollution and indicates geogenic, rather than anthropogenic, metal sources.

However, bacteriological analysis revealed serious contamination that undermined the water's suitability for domestic purposes. Total coliform counts (9.5–24 MPN/100 mL) and the presence of Escherichia coli in 70% of samples far exceeded WHO standards, which stipulate zero tolerance for faecal coliforms in drinking water. Similar contamination levels have been reported in Nigeria. Odewade *et al.* (2025) detected *Escherichia coli*, *Shigella dysenteriae*, and *Salmonella typhi* in groundwater from Funtua, attributing the contamination to poor sanitation and latrine seepage. In this study, the detection of *S. typhi* and *Vibrio cholerae* (each in 30% of samples) signifies faecal pollution from human or animal waste. This finding corroborates the epidemiological evidence from Dan-Nwafor *et al.* (2019), who linked a cholera outbreak in rural north-central Nigeria to *V. cholerae* contamination of community water sources. Similarly, Fagbamila *et al.* (2023) identified unsafe water consumption as a key risk factor for cholera in Nigeria's northeastern region. The isolation of other bacterial species, such as *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Staphylococcus aureus*, indicates multiple contamination routes, including agricultural runoff and poor water management. These results are consistent with those of Adeyemi *et al.* (2019), who found high *E. coli* and coliform densities in wells near septic tanks in Osogbo, Osun State, confirming that proximity to waste systems increases the risk of contamination of well water.

Water quality is vital for sustainable development in Pindiga, where groundwater serves as the primary drinking water source. This study revealed the challenges posed by natural and human activities that affect the water quality. The Water Quality Index provides a thorough evaluation aligned with SDGs 6 and 3 for clean water and health. The present findings contradict those reported by Agori *et al.* (2024) and Ibe *et al.* (2019), yet they correspond closely with the observations of Amaibi *et al.* (2022). In a related investigation, Machona *et al.* (2025) documented that 5 % of the analysed water samples were categorised as excellent, 25 % as good, 15 % as very poor, and 55 % as unsuitable for human consumption. This sharply contrasts with the outcome of the current study, in which all sampled points (100 %) were classified as unsuitable for drinking. Compared with findings from other regions, the water quality in Pindiga Pond is a more critical condition; for example, Atta *et al*. (2022) reported that 35.8 % of groundwater samples were rated excellent, a standard not attained at any sampling point in the present investigation. This difference reflects high industrial activity and insufficient infrastructure to safeguard water sources from pollution, highlighting the need for policy measures to improve water quality, particularly in Pindiga, where industrial operations continue to affect the water resources.

When compared with the WHO (2008) and NSDWQ (2007) standards, the physicochemical parameters of the Pindiga Pond largely complied with acceptable thresholds, except for Fe and DO. Statistical analyses confirmed significant variations ($p < 0.05$) in TDS, turbidity, and bacterial counts among the sampling sites, reflecting localised pollution influences. These patterns are consistent with the findings of Odewade *et al.* (2025) and Popoola *et al.* (2024), who observed site-specific contamination linked to agricultural activities and sanitation deficiencies. The physicochemical stability of pond water contrasts sharply with its bacteriological instability, demonstrating that microbial contamination remains the most critical challenge in rural Nigerian water systems. The main limitation of this study is its short sampling period and the absence of seasonal variation data, which may influence the bacterial and oxygen dynamics. Future research should incorporate year-round sampling, molecular pathogen detection, and spatial modelling to map contamination pathways. Establishing a community-based water safety plan, following the WHO guidelines, would significantly improve the water quality and reduce the disease burden in rural Gombe State.

CONCLUSION

This study showed that Pindiga Pond, a domestic water source situated in Akko L.G.A., Gombe State, exhibited generally acceptable physicochemical properties; however, it was significantly compromised by bacterial contamination. Key parameters, such as pH, turbidity, total dissolved solids, and electrical conductivity, met the WHO (2008) and NSDWQ (2007) standards, whereas low dissolved oxygen and high iron concentrations suggested organic pollution and geogenic influence. The isolation of *Escherichia coli*, *Salmonella typhi*, and *Vibrio cholerae* confirmed faecal contamination and presented a high risk of waterborne infection. There were significant spatial variations in contamination, particularly in areas near agricultural and residential activities near the river. Although the Pindiga Pond water appears chemically suitable for human consumption, it is microbiologically unsafe without adequate treatment. Immediate interventions, including regular water quality monitoring, improved sanitation, community awareness programs, and the establishment of a local water safety management plan, are crucial for protecting public health and ensuring sustainable water use.

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